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IN-MEDIUM EFFECTS IN K^+ SCATTERING VERSUS GLAUBER MODEL WITH NONEIKONAL CORRECTIONS

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The discrepancy between the experimental and the theoretical ratio R of the total cross sections, $R = \sigma(K^+ - {}^{12}\mathrm{C})/6\sigma(K^+ - d)$, at momenta up to 800 MeV/c is discussed in the framework of the Glauber multiple scattering approach. It is shown that various corrections such as adopting relativistic K^+–N amplitudes as well as noneikonal corrections seem to fail in reproducing the experimental data especially at higher momenta.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

Ядерные эффекты в K^+-рассеянии и модель Глаубера с неэйкональными поправками

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Отношения сечений $R = \sigma(K^+ - {}^{12}\mathrm{C})/6\sigma(K^+ - d)$ вычисляются по модели Глаубера вплоть до импульсов 800 МэВ/с с использованием релятивистских K^+–N-амплитуд. Показано, что даже после введения неэйкональных поправок не наблюдается согласия с экспериментальными данными. Указано на возможные ядерные эффекты типа EMC.

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1. Introduction

One of the most important subjects discussed at present, is the problem of confinement of quarks in hadrons and the difficulties associated with the long distances in QCD. From QCD we know that at a sufficiently dense matter, which may be obtained in high energy nucleus-nucleus collisions, colour screening will lead to quark deconfinement. However, the EMC effect indicates that nucleons can significantly charge their properties even in the ground state of nuclei. At present, inclusion of such unconventional EMC-type effects receives greater attention in contemporary nuclear physics.

To explore the nuclear interior, the K^+-meson was then regarded as a unique probe due to its long mean free-path in the medium [1—5]. However, theoretical predictions for its

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total cross section based on the conventional nuclear physics approaches failed to reproduce the experimental data [4,5]. This situation triggered the search for the role played by the medium in modifying hadronic properties [6—11]. Thus, exotic mechanisms to describe the K^+ data such as nucleon *swelling* (or partial deconfinement of nucleons), in-medium modification of meson properties, and excess of pions in nuclei are still the source of considerable debate (see, e.g., [6,10]).

We believe, however, that a careful analysis should be performed before any conclusion can be drawn as to the necessity of introducing features that are not present in the standard nonrelativistic models.

Since Glauber's multiple scattering theory [12] has been applied very successfully in the past for various hadronic probes at intermediate energies, it may be of interest to try to apply it for the above case of K^+ scattering [11] as well. We further extend such calculations by taking into account noneikonal effects [13,14] as well as relativistic K^+-nucleon amplitudes [15].

Thus far, our work serves largely to confirm other approaches based on various optical model potentials [4,5], and gauges the need for exotic mechanisms.

2. Glauber Model Analysis

Although the Glauber theory was developed initially for high energy projectiles, yet it also successfully works in the intermediate energy region.

In the present work, however, we shall include as well the so-called noneikonal effects (i.e., the deviation from the simple eikonal propagation picture) in our calculations.

For the sake of clarity, we recall that following Glauber, the amplitude for a projectile-target elastic scattering, assumes the general form:

$$f(Q) = \frac{ik}{2\pi} \int e^{i\,\mathbf{Q}\cdot\mathbf{b}}\,[1 - e^{i\,\chi(\mathbf{b})}]\,d\,\mathbf{b}, \tag{1}$$

where b is the impact parameter and χ is the corresponding phase shift function.

More explicitly, for projectile-nucleus scattering, Eq.(1) can be cast in the form:

$$F(Q) = \frac{ik}{2\pi} \int e^{i\,\mathbf{Q}\cdot\mathbf{b}}\,\langle[1 - e^{i\,\chi(\mathbf{b},\,\mathbf{s}_1,\,\ldots,\,\mathbf{s}_A)}]\rangle\,d\,\mathbf{b}, \tag{2}$$

where $\mathbf{s}_j$ is the component of the radius-vector $\mathbf{r}_j$ of the j^{th} target nucleon in the direction perpendicular to the incident momentum $\mathbf{k}$, while the brackets $\langle\,\rangle$ denote target ground-state average.

Further, given the corresponding projectile-target nucleon amplitudes,

$$f(q) = \frac{k(i+\gamma)\,\sigma}{4\pi}\,e^{\beta^2 q^2/2}, \quad \gamma = \mathrm{Re}\,f(0)/\mathrm{Im}\,f(0), \tag{3}$$

and σ is the projectile-target nucleon total cross-section, then one can express the above projectile-target nucleus amplitude in the following parameter-free way:

$$F(Q) = ikG(Q) \int bdbJ_0(Qb) \times$$
$$\times \left\{ 1 - \left[1 - \frac{1}{2\pi ik} \int e^{-i\mathbf{q}\cdot\mathbf{b}} f_p(q)\, S_p(q)\, d\,\mathbf{q} \right]^Z \times \right.$$
$$\left. \times \left[1 - \frac{1}{2\pi ik} \int e^{-i\mathbf{q}\cdot\mathbf{b}} f_n(q)\, S_n(q)\, d\,\mathbf{q} \right]^N \right\} \qquad (4)$$

here $S(q)$ is the nuclear form factor, N, Z are the numbers of neutrons and protons in the target nucleus, while $G(Q)$ is the corresponding c.m. correlation factor. Since in the present work we are interested in total cross sections, then we need only to calculate $F(Q)$ at $Q = 0$, and in this case $G(0) = 1$. It is then a straightforward matter to obtain the total cross section for the case of K^+-target nucleus scattering adopting the optical theorem.

In the above equations, the parameters σ, β, and γ of K^+–N amplitudes at different energies will be taken from the data (see [11]) while we adopt for the elementary amplitudes f Martin's (relativistic) phase shifts [15], which give very reliably results up to momenta 1 GeV/c [16]. For this purpose, we elaborated a special code for the calculation of K^+–N partial wave amplitudes (S, P, D, and F states) with the corresponding isospins ($I = 0$, $I = 1$) .

For $N = Z$ nuclei, we thus utilized the following average K^+–N amplitudes

$$f(K^+N) = \frac{1}{2}\,[f(K^+p) + f(K^+n)]. \qquad (5)$$

In a previous work [11] we have calculated the above total cross sections directly from Eq.(4), but we have found, however, that the same result is almost obtained with even the more simplified (optical-limit) form:

$$\sigma_{K+A} = 2\pi \int_0^\infty \mathrm{Re}\,[1 - e^{i\,\chi(b)}]\, bdb, \qquad (6)$$

where $\chi(b)$ is the nuclear phase function.

Further, to relate the above formulation to the usual semiclassical approaches, it is generally accepted to consider the Glauber phase-shift function as the eikonal approximation of an equivalent optical model potential. However, for potential scattering an eikonal expansion has been given in a compact form by Wallace et al. [13] and by Waxman et al. [14] viz:

$$\chi(b) = \sum_n - \frac{\mu^{n+1}}{k(n+1)!} \left(\frac{b}{k}\frac{\partial}{\partial b} - \frac{\partial}{\partial k}\frac{1}{k} \right)^n \int_0^\infty V^{n+1}(r)\, dz. \qquad (7)$$

The zeroth order term in such an expansion $\chi(b)_{\mathrm{eikon}}$ is just the Glauber eikonal phase, while the n-order correction $\chi(b)_{\mathrm{noneik}}$ gives rise to noneikonal effects.

To that end, we have used in our calculations Glauber's eikonal approximation as well as the first and second order noneikonal corrections to this approximation, i.e.,

$$\chi(b) = \chi(b)_{\text{eikon}} + \chi(b)_{\text{noneik}} \, . \tag{8}$$

For the carbon density the following harmonic oscillator wave functions were used, with the parameters of Ref. [17], where the nucleon size has been properly taken into account:

$$\rho(r) = (\alpha + \beta r^2)\, e^{-\gamma r^2}, \quad \alpha = \frac{4}{\pi^{1.5}/R^3}, \quad \beta = \frac{2(A-4)}{3A\,\pi^{1.5} R^5}, \quad \gamma = \frac{1}{R^2}, \tag{9}$$

where $R^2 = 2.5 fm^2$ [17].

In the figure below we show the experimentally determined [3—5] ratio R and the different theoretical predictions. The dotted line represents the results of this work, and is obtained using the Glauber eikonal approximation (see text). The dot dash line corresponds

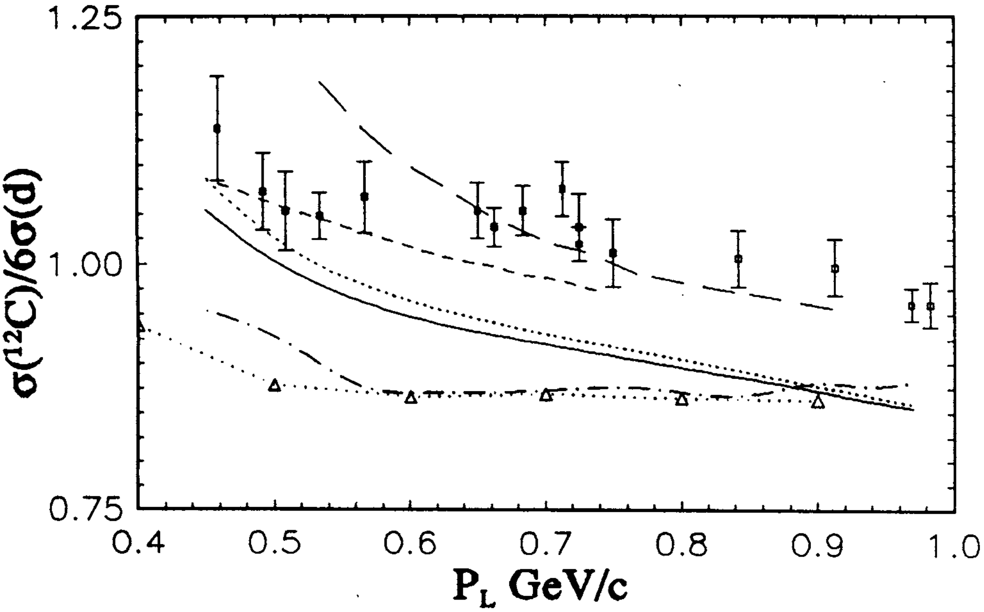

Fig. Comparison of data [3,4,5] and different models for the ratio R (see text); dotted line — this work (eikonal approximation); solid line — this work including noneikonal corrections; dot dash line — Glauber model from Ref. [11]; long dash line — swelling model [7]; short dash line — MEC model [8,9]. By triangles we show the calculations using the momentum-space optical model potential [10] to our previous analogous calculations [11], using the usual high-energy approximation as given by Eq.(4). It seems that there is close agreement between the above two approaches. Solid line displayes the results including noneikonal corrections (see, Eq.(8)). The results of the momentum-space optical model potential of Ref.[10] are represented by triangles.

It is interesting to note here, that the first order noneikonal correction lowers our cross section ratios in the considered range of the projectil's momenta, while the second order correction results in bringing that ratio more closer to Glauber's result. This seems to be extremely interesting as thise corrections are intended to improve upon the eikonal result bringing it more closer to its exact quantum mechanical counterpart. Thus, care should be exercised when dealing with noneikonal corrections.

As can be seen from our figure, all the eikonal as well as the optical model results fail in reproducing quantitatively the ratio R. This situation then led many authors to assume some exotic phenomena ranging from nucleon swelling to pion excess in nuclei [8,9]. However, the results based on such phenomena still do not lead to a satisfactory agreement with the experimental data as can be read from the figure.

We conclude that both our results, the results calculated in the framework of the optical model and also suggestions about nucleon swelling [6] as well as pion excess in nuclei [8,9], show the possibility of observing some unusual phenomena in K^+-nucleus interaction. But the investigation of the in-medium effects in the theory of nuclear reactions is still in its early stages and it needs more time to clarify and isolate exactly the role played by the nuclear medium in relevance to phenomenon as that described above.

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